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Design Issues Concerning Iran's Bushehr Nuclear Power Plant VVER-1000 Conversion

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INTRODUCTION

On January 8, 1995 the Atomic Energy Organization of Iran (AEOI) signed a contract for $800 million with the Russian Ministry of Atomic Energy (Minatom) to complete Bushehr Nuclear Power Plant (BNPP) Unit 1.[1] The contract called for a Russian VVER-1000/model 320 PWR successfully installed into the existing German-built BNPP facilities in five years. System design differences, bomb damage, and environmental exposure are key issues with which Minatom must contend in order to fulfill the contract.

The AEOI under the Shah of Iran envisioned Bushehr as the first of many nuclear power plants, with Iran achieving 24 GWe by 1993 and 34 GWe by 2000. Kraftwerk Union AG (KWU) began construction of the 2-unit, 2600-MWe plant near the Persian Gulf town of Halileh in 1975. Unit 1 was about 80 percent complete and Unit 2 was about 50 percent complete when construction was interrupted by the 1979 Iranian Islamic revolution. Despite repeated AEOI attempts to lure KWU and other companies back to Iran to complete the plant, Western concerns about nuclear proliferation in Iran and repeated bombings of the plant during the 1980-1988 Iran-Iraq war dissuaded Germany and other Western countries from assisting in construction.

GERMAN CONVOY AND RUSSIAN VVER

The unprecedented plans by AEOI and Minatom to install a reactor in facilities built by another vendor and repeatedly attacked in war, raise serious design-related issues that are explored in this paper. Although the German KWU and smaller Russian VVER reactors share many similar design features, significant differences in design make successful conversion questionable. This paper examines the two PWR designs and highlights key differences that will strongly impact conversion. Lack of precise information on bombing and environmental damage preclude more than general comments on those issues.

The BNPP KWU 1300-MWe PWRs are early versions of the “Convoy” family of KWU reactors. Reactors similar to BNPP include Grafenreinfeld and Biblis B in Germany, and Brazil’s Angra-2 and -3.[2,3] Isar-2 , Emsland, and Neckar-2 are standard Convoy reactors in Germany . The standard KWU system design was modified to accommodate Bushehr’s greater seismic activity, higher ambient thermal conditions, and a generally more hostile environment than (compared to) Germany.[4]

The Russian VVER-1000 was designed in the 1970s, made its debut as model 187 in 1980 at Novovoronezh-5, and was followed by models 302 and 338 deployed at four plants. Thirteen of the more modern VVER-1000/320 reactors are operating: the first 320 was deployed at Balakova-1 in 1985, and the newest went critical at Ukraine’s Zaporozhye-6 in October 1995. The many design parameters compiled and analyzed for this study are shown in Table 1;[4,5] especially noteworthy design differences are discussed below.

PROSPECTS FOR COMPLETING BUSHEHR UNIT 1

Although designed for a cylindrical containment building, the VVER-1000 nuclear steam supply system (NSSS) will probably physically fit within the KWU 56 m spherical reactor containment building. The standard KWU NSSS is designed to fit within a 40 m diameter cylindrical concrete wall which defines the reactor confinement zone, while the VVER NSSS requires about a 37 m diameter envelope. BNPP Unit 1 successfully completed a containment pressure test in 1978, but reportedly very few, if any, of the primary loop components were installed.[6-10] Thus, Minatom can probably proceed with NSSS design without modifying the VVER design to incorporate KWU NSSS components, or removing major KWU components. Nevertheless, the VVER must interface with the KWU-built buildings and any already-installed reactor auxiliary systems. A major challenge for Minatom will be installing four horizontal steam generators into a facility designed for four vertical steam generator, which will probably require concrete demolition. AEOI and Minatom signed a separate $140 million contract for foundation reconstruction several months after the initial contract.[11]

It appears that the VVER-1000 turbine-generator (T-G) set will not fit in the BNPP T-G building; the BNPP turbine building dimensions are about two-thirds that of the standard VVER-

1000/320 turbine building. If the KWU T-G set is not already installed at BNPP, Minatom must develop plans to install either a single 1000 MW T-G, or two 500 MW T-G sets; both configurations have been used at other VVER-1000 plants.

ADDITIONAL COMMENTS

The outer concrete shell for Unit 1 was not completed, leaving the steel containment sphere exposed to environmental and military hazards. Despite being attacked by Iraq on at least ten separate occasions,[12-14] reports of BNPP bomb damage are vague. Some reports mention damage to the plant being greater than earlier believed, with some shells penetrating sections of the steel containment.[15,16] Additionally, damage to equipment and facilities from exposure to the harsh Persian Gulf environment could be significant.

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TABLE 1

Comparison of KWU and VVER Reactor Systems

DESIGN PARAMETER	KWU BUSHEHR DESIGN VALUE	VVER-1000/320 DESIGN VALUE
OVERALL SYSTEM		
Reactor containment diameter/height [m]	56 (sphere)	48/54
Overall containment building diameter/height [m]	60/61	66 (square)/74
Containment design pressure [MPa];Temperature [_C]	0.63; 145	0.414; 150
Gross thermal power [MWt]	3765	3200
Electric power gross/net [MWe]	1293/1196	1000/950
NUCLEAR STEAM SUPPLY SYSTEM (NSSS)		
Reactor pressure vessel diameter (inner/outer) [m]	5.0/5.5	4.1/4.6
Reactor pressure vessel height (head flange/control rod drive nozzles) [m]	10.0/12.4	10.9/12.2
Reactor pressure vessel mass, empty [t]	450	304
Active core height [m]	3.9	3.55
Number of fuel assemblies/Rods per assembly	193/236	163/330
Total uranium in core [t]	103	66
Number of control assemblies	61	109
Number of reactor main coolant circuits	4	4
Reactor coolant inlet/discharge temperature [_C]	291/326	289/322
Reactor coolant pressure [MPa]; Total coolant flow rate [m^3/s]	15.8; 18.8	15.8; 21.1
Primary coolant pump overall dimensions [m]	2.5 D x 7.0 H	5.0 D x 11.9 H
Pressurizer dimensions [m]	2.6 D x 13.2 H	3.0 D x 13.6 H
Steam generator; number and type	4, vertical U-tube	4, horizontal U-tube
Steam generator mass, empty [t]	447	321
Steam generator steam production rate [kg/s]	515	408
BALANCE OF PLANT		
Secondary circuit coolant inlet/discharge temperature [_C]	218/284	220/279
Secondary coolant circuit pressure [MPa]	6.87	6.48
Moisture separator and reheater dimensions [m]	4.4 D x 16.5 H	3.95 D x 13.35 H
Turbine configuration Turbine rotational speed [rpm]	1 HP, 2 LP 1500	1 HP, 1 IP, 2 LP 1500
Generator power rating [MVA] Terminal output power [MW] Voltage [kV] Frequency [Hz]	1620 1314 27 50	unk. 1030 24 50
Turbine-generator set overall length [m] Turbine generator building dimensions [m]	54 80 x 40	80 120 x 66
Condenser cooling water temperature [_C]; Condenser pressure [MPa]	30; 0.0101	22; 0.006

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